CONFERENCE OF THE COMMITTEE ON DISARMAMENT

CCD/323
18 March 1971
Original: ENGLISH

THE NETHERLANDS

Working Paper concerning seismic detection and identification of underground nuclear explosions

1. Introduction

The Netherlands Delegation to the Conference of the Committee on Disarmament has considered the materials presented to this Body on the question of the detection, location and identification of underground nuclear explosions, together with the relevant data from open literature. The delegation thought it worthwhile to summarize the data most pertinent to this question in order to facilitate discussions. It has summarized a substantial part of these data in two figures reproduced in this paper.

The excellent Canadian report of November 1970 on Seismological Detection and Identification of Underground Nuclear Explosions by P.W. Basham and K. Whitham has been the main source of the information presented in the figures, including the magnitude-yield relation.

2. Existing capabilities

A summary of the existing seismic capabilities for identification of underground nuclear explosions, especially in the Northern Hemisphere, is given in the upper part of Figure 1. More detailed information for the different test sites is given in Figure 2.

In both figures a detection and location capability for earthquakes (Q) and explosions (E) is indicated where there is a 90 per cent probability that each of at least four seismic monitoring stations can detect and locate the earthquake or explosion by measuring the body (P) wave. In the Northern Hemisphere the lower limit of this detection and location capability (indicated by 4P90) for earthquakes and explosions is between magnitude m_B-values of 4.2 and 4.4. This corresponds to an explosion yield of about 3 kiloton in hard rock. The P-wave detection capability is given by thin lines in fig. 1.

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The capability to identify earthquakes and explosions is presented in the form of bars in the figures. This discrimination between earthquakes and explosions is based on the surface (R) wave/body (P) wave ratio, which is quite different for the two kinds of events. Positive identification of earthquakes is possible for m_B-values of 4.8-5.1, while for explosions this is 5.8-6.1. The possibility of positive identification is interpreted here as a 90 per cent probability that each of at least four seismic monitoring stations can identify at this threshold value the earthquake or explosion as such by measuring the amplitudes of the R-wave and P-wave. This capability is indicated by 4R90 in the figures.

In connexion with a comprehensive test ban, lower identification probabilities for explosions are also considered. In figure 1 these are presented in the form of bars for a 50 per cent and a 20 per cent probability of identification by four stations each. For example, the identification threshold is lowered to m_B 5.1-5.4 at the 20 per cent probability level for each of four stations (4R20). In figure 2 other identification probabilities are also given.

Another possibility to identify an explosion can be found by using a "negative" criterion, that is the absence of R-waves when one would expect these in the case of an earthquake. An estimate of this identification capability is indicated in fig. 1.

From the upper part of figure 1 it can be concluded that the present seismic monitoring system in the Northern Hemisphere can identify with a reasonable probability explosions with a magnitude m_B 5.5 or a yield of about 50 kton in hard rock. Earthquakes can be identified above m_B 4.8-5.1 with a high degree of confidence.

3. Potential capabilities

Several methods to increase the identification capabilities for underground nuclear explosions have been proposed and/or are investigated at present (see the lower part of fig. 1).

a. Specific studies of events at the Nevada Test Site have made clear that, by a study of R_g-waves, an identification threshold of m_B 5.0 may actually be reached. R_g is the surface wave, guided within the continental part of the earth crust only, and consequently restricted to purely continental source-receiver path ways. It seems likely that with the existing station network this type of wave could effectively be used for other continental test site - station combinations.

b. In theory the ratio of the body (P) wave frequencies can be used down to the level of its detection, which should mean to magnitude m_B-values of 4.2-4.4. In practice this method, which makes use of the (spectral) characteristics of the measured body (P) wave itself (thus not using a combination of body (P) and surface (R) waves), has at least been realized down to m_B 4.9 for certain test site-station combinations. It seems likely that the highly successful work on this P-wave spectral ratio discriminant, as developed by the United Kingdom research group, by additional studies could be extended to magnitude values nearer to the threshold of P-wave detection. In any case the method can be used without undue extension of the present seismic monitoring system.

c. An important capability increase could be achieved by the use of the new high-gain long-period vertical seismometer (LPZ), as developed by research groups in the United States of America. Using these instruments the surface (R) wave spectral ratio criterion can be extended down to a magnitude of 5.3 and the R-wave/P-wave ratio method down to m_B 4.9. Moreover, the absence of surface (R) waves in the records of this instrument may constitute an important indication for the explosion character of an event down to m_B-values of 4.4, which corresponds with a hard-rock yield of about 4 kton. The installation of a limited number of high quality high gain LPZ recorders could thus become of major significance in improving the identification system.

d. The last mentioned threshold values are of the same order as envisaged to be reached by the 26 extended seismic array system as described by the United Kingdom Delegation in document CCD/296. It can be expected however that the 26 array system will be much more expensive than the installation of a limited number of LPZ instruments.

In fig. 1 (lower part) estimates of the potential capabilities of the different systems are indicated. At present no exact identification probabilities can be given.

4. Additional identification improvements

a. A better and more detailed structural analysis of the crust and upper mantle of the earth should help in lowering the existing threshold values by a more effective use of the "matched filtering" process. A gain of 0.2 magnitude units has been obtained for some of the test site - station combinations. Eventually this same gain could be reached for any other place in the Northern Hemisphere, which would mean a lowering of the threshold yield value by a factor of 2/3.

b. Knowledge of the predominant type of radiation of seismic waves in the seismic zones of the earth could be of great importance in the interpretation of the records of an event of unknown type. The identification of earthquakes will be made more effective and herewith the discrimination against underground nuclear explosions.

c. For the understanding of the processes of energy transfer in earthquakes and explosions additional studies on the magnitude-yield relation of explosions in different types of media are needed. The question has already been raised if the use of surface wave magnitudes is not to be preferred to the body wave magnitude-scale m_B which is normally used in this work. It seems likely that a more consistent explanation of the data, and therewith of the identification of suspected events, might be reached.

d. Other, non-seismic, methods of detection of underground nuclear explosions, have been envisaged. Cratering occurs for explosions of about 20 kton and more in thick layers of dry soil, as mentioned in the SIPRI report [1] (see also fig. 1). Extensive mining works are necessary for the seismic decoupling of underground explosions in hard rock, although it is unclear whether such decoupling is possible for interesting yields. Both cratering and mining can probably be detected by satellites.

A multi-variate analysis of the whole scale of possibilities mentioned above inevitably will lead to an increase of the weight of the conclusions based on the individual methods.

5. Suggestions

The work on the P wave spectral ratio, as developed by the United Kingdom, should be elaborated and extended to lower magnitude events.

The installation of an appropriate limited network of high gain LPZ instruments, as developed by the United States of America, could be particularly helpful.

Additional study of crust and upper mantle structure, and of the radiation characteristics of shallow earthquakes in regions that in future could be used as test-sites, should be encouraged.

Support should be given to studies directed to the solution of the magnitude-yield relation in different types of media, and to the question of seismic efficiency.

1/ Seismic methods for monitoring underground explosions, SIPRI, Stockholm Papers no. 2.

6. Conclusions

It has been shown that the existing, more or less routine-based, facilities can identify 50 kton events in hard rock. By the inclusion of other types of discriminants this identification in principle could be extended to hard-rock yields of 10-20 kton, using the present monitoring system. With an additional installation at selected places of high gain LPZ seismometers another threshold reduction of a factor of two might be realized.

Also in that case, however, a supposed test-ban treaty could be evaded by a test programme of yields of 10 kton and less in dry soil that, in the case of sufficient thickness of the layer, will remain undetected and unidentified by seismological means or by observations of cratering.

With the most optimistic views in mind on the future development of seismic identification techniques, it can still be said that this 10 kton threshold will not be lowered within the next five years.

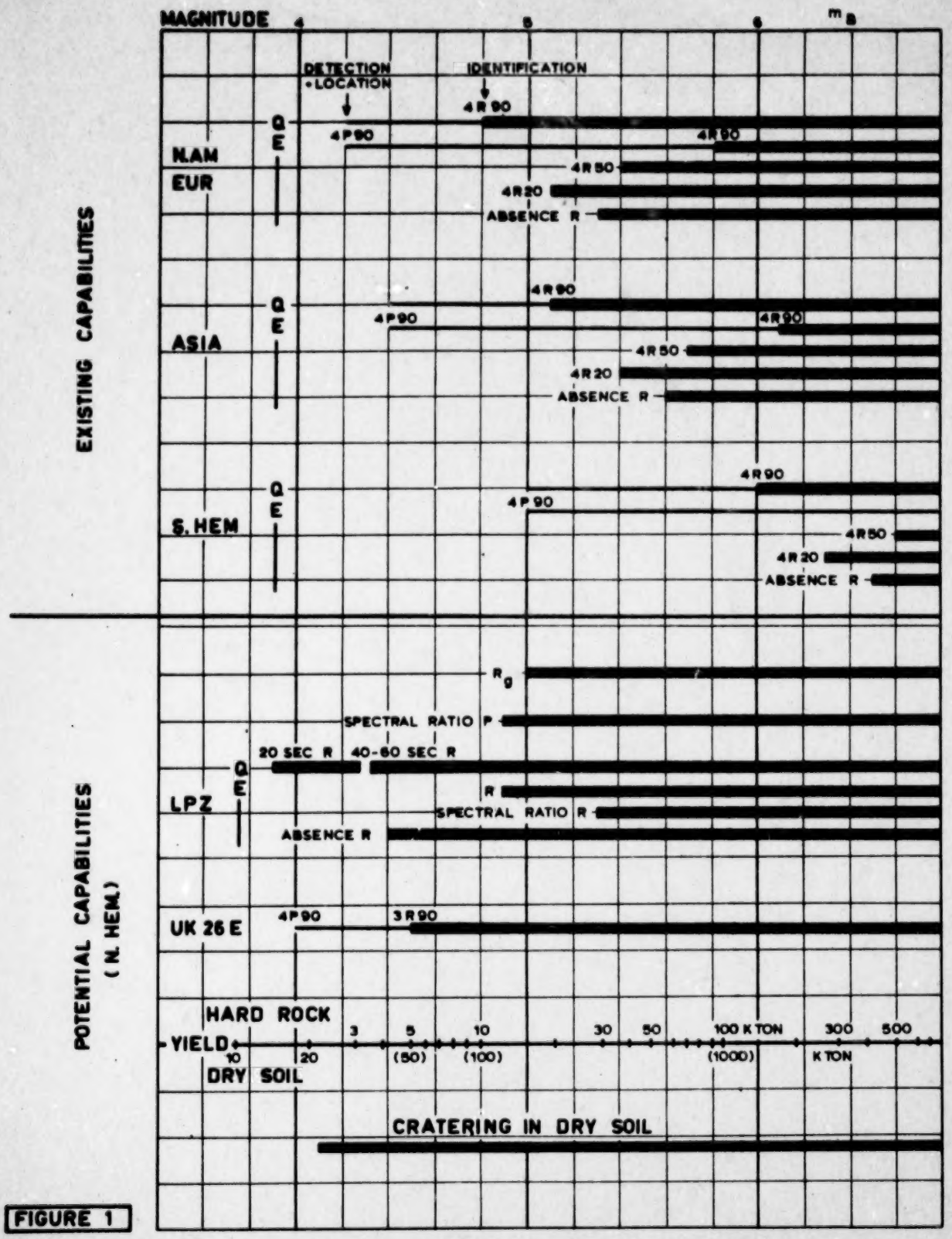
MAGNITUDE
4
5
6
m_B
DETECTION
• LOCATION
IDENTIFICATION
EXISTING CAPABILITIES
Q
E
N.AM
4R90
4P90
4R90
4R50
EUR
4R20
ABSENCE R
Q
E
ASIA
4R90
4P90
4R90
4R50
4R20
ABSENCE R
Q
E
S. HEM
4R90
4P90
4R50
4R20
ABSENCE R
POTENTIAL CAPABILITIES (N. HEM.)
R_g
SPECTRAL RATIO P
Q
E
LPZ
20 SEC R
40-60 SEC R
R
SPECTRAL RATIO R
ABSENCE R
UK 26 E
4P90
3R90
HARD ROCK
YIELD
3
5
10
30
50
100 K TON
300
500
10
20
(50)
(100)
(1000)
K TON
DRY SOIL
CRATERING IN DRY SOIL

FIGURE 1

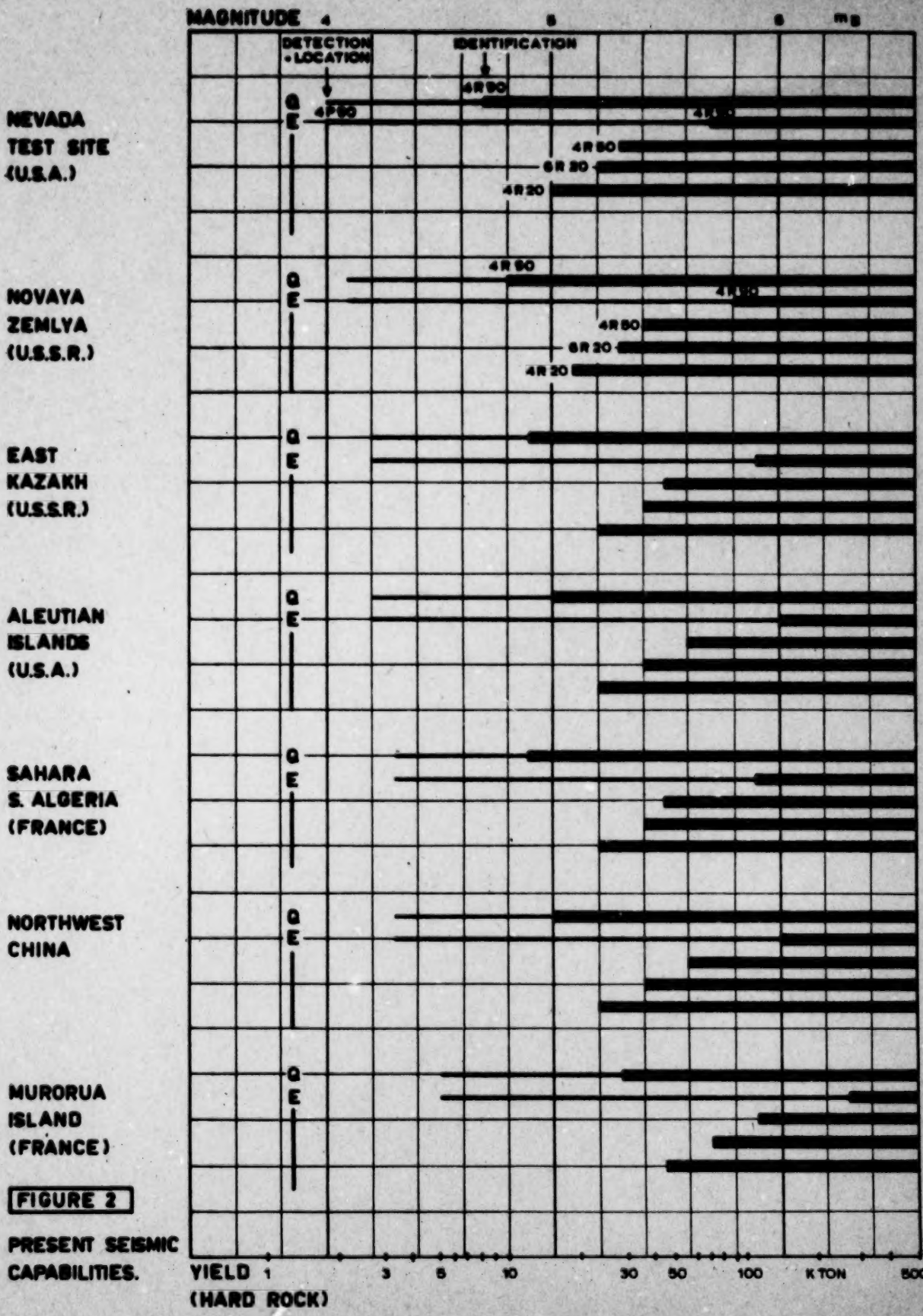

FIGURE 2

PRESENT SEISMIC CAPABILITIES.